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July 1987

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# Equipment for non-destructive diagnoses of pellets in flight

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## Abstract

A non-destructive method to measure the mass and velocity of a pellet in flight has been demonstrated. Basically it has been developed for frozen deuterium pellets to be injected into a tokamak plasma, but it has general application to measure the mass a d velocity of pellets made of dielectric material.

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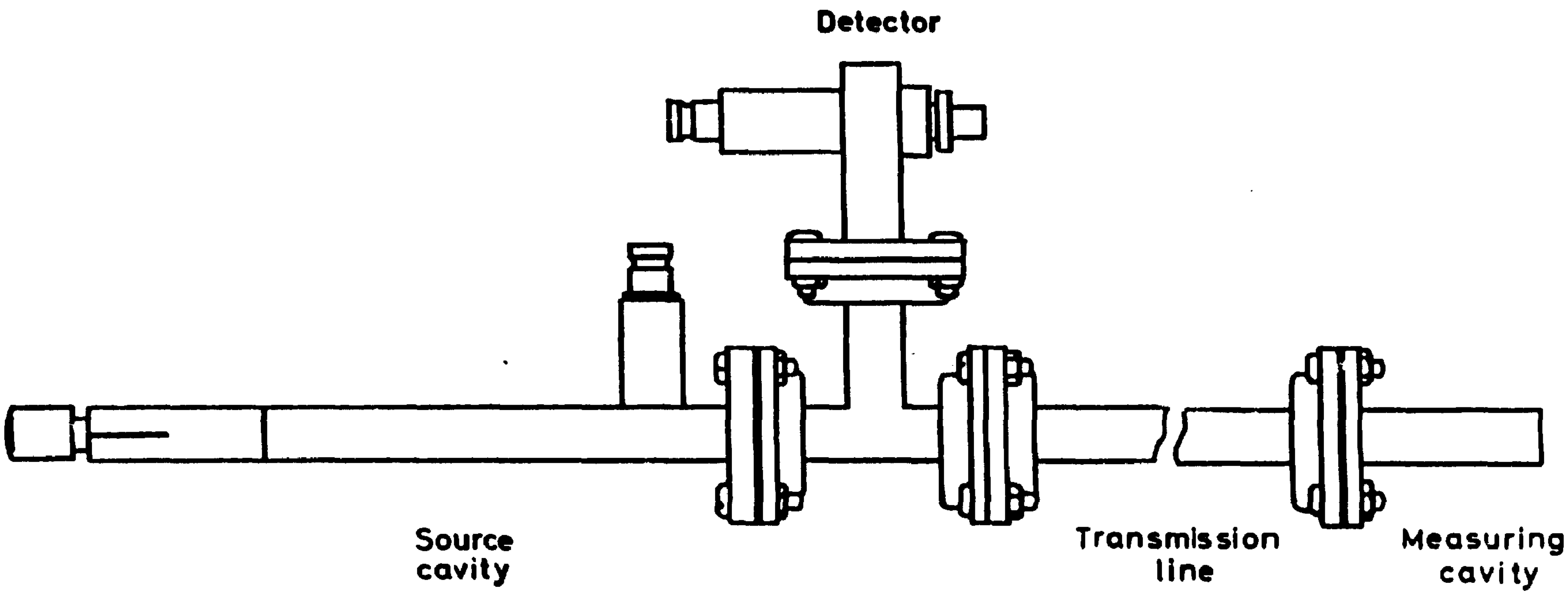
## Introduction

The method of measuring the mass of a frozen deuterium pellet in flight by letting it influence the electromagnetic field in a microwave cavity is by now well-known[1]. Equipment using this principle has been delivered by Risø to be used at ASDEX, Eta-Beta II, the pellet group at Grenoble, and at JET[2]. The same type of equipment is built and used combined with pellet injection in tokamaks in U.S.A.[3]. The principle of the microwave set-up is shown in Figure 1. It is built up by a source cavity mounted with a Gunn-diode as the active oscillating element, a transmission line mounted with a detector arrangement, and a measuring cavity with openings to enable the pellet to pass. The length of the transmission line may be just sufficient to allow space for the detector system in very compact set-ups, and up to about 20 m, if it is necessary to keep the active elements, Gunn-diode and detector-diode, away from damaging environments. The accuracy of these systems for mass measurement is about 5%.

To find the velocity of the pellet it is necessary to know the position of the pellet at two well-defined times. This may be done by using two optical systems. If radiation is present, the optical detectors have to be placed at a sufficient distance to avoid damage, this may be accomplished with long light-guides. To simplify the




<u>Figure 1.</u> Principle of the microwave set-up with source cavity, transmission line, and measuring cavity. The transmission line may be from a few cm up to several meters long.

set-up, the signal from one of the optical systems may be replaced by the "size-signal" from the microwave set-up, as has been used in the pellet diagnostic equipment made for JET[2]. Using a long transmission line for the microwaves, the optical system may be completely avoided if the pellet is allowed to pass the microwave tube, not only in the measuring cavity, but also directly in the transmission line in order to have another timing signal (see Figure 2). This possibility has been discussed previously with indication of the problems encountered with the size of this timing signal if the transmission line is very long[4]. These problems may be overcome by letting the pellet pass another cavity mounted on a side-branch on the transmission line, as suggested in the same reference. It is possible to set up such a system, but the tuning is rather difficult. A system with only one measuring cavity is much simpler to place into operation, and such a system that is still able to measure the mass as well as velocity of pellet will now be discussed.

## Experimental set-up and results

In principle the new system is similar to the one shown in Figure 1, but the measuring cavity that originally was a piece of WG 16 waveguide, with a length corresponding to one-half wavelength, is now replaced by a cylindrical tube 3.55 cm in diameter, and of a length that supports several wavelengths of a standing wave. (The new set-up

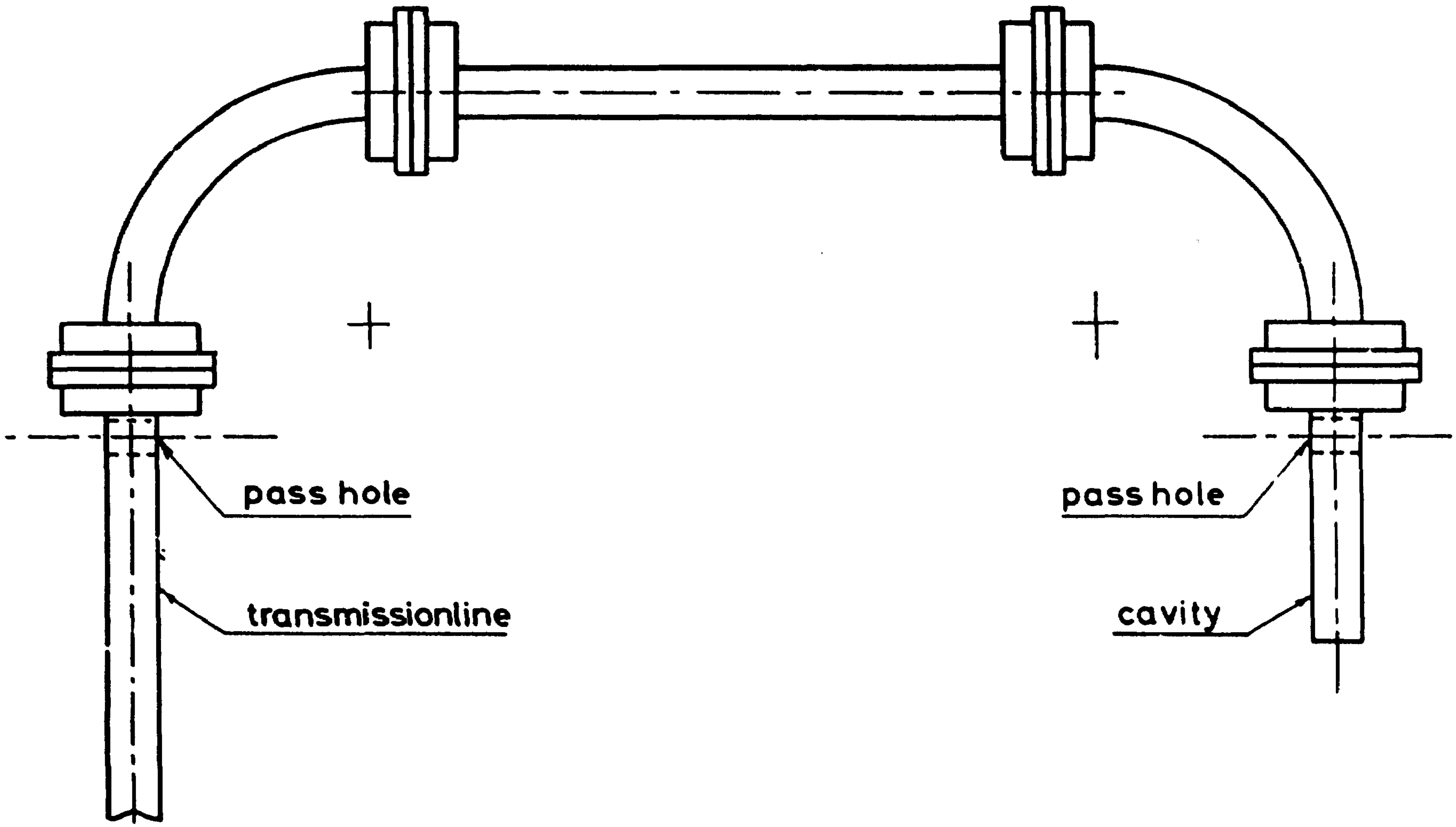



**Figure 2.** Sketch showing the idea of the set-up with double interaction of the microwave system.

is shown in Figure 3.) The Gunn-diode mounted in the source cavity may oscillate in the frequency range 8 - 9 GHz, and the system is normally tuned to 8.6 GHz. At this frequency it is possible to excite the two fundamental modes $TE_{11}$ and $TM_{01}$ in the cylindrical cavity. These modes are seen as the lowest ones in the mode chart in Figure 4. The length of the cavity determines which mode to excite. With the given values of frequency and cavity diameter, we find $(fD/10^4)^2$ to be 9.32. From the mode chart it is now seen that one-half wavelength of $TE_{11}$ and $TM_{01}$ will need 2.17 and 2.65 cm, respectively. The ratio between the diameter of the tube and length of one-half wavelength for the two modes, respectively, show that for the given frequency the choice of tube diameter is reasonable in respect of Q-value for the cavity[5].

The length of the cavity is given by the positions of two movable diaphrams situated in the tube as end walls. Now the cavity may be tuned to resonance for an arbitrary number of half wavelengths. If holes are drilled at the end walls centered on the tube axis, a pellet may pass the cavity along this axis. If the cavity is slightly mistuned to operate on the flank of the resonance peak, the entrance of a pellet will strongly influence the interaction between the cylindrical cavity and the transmission line feeding it. The change in interaction will be expressed by the detector mounted in a side branch on the transmission line. Examples of the signal from a passing pellet is shown in Figures 5 and 6 for the $TE_{11}$

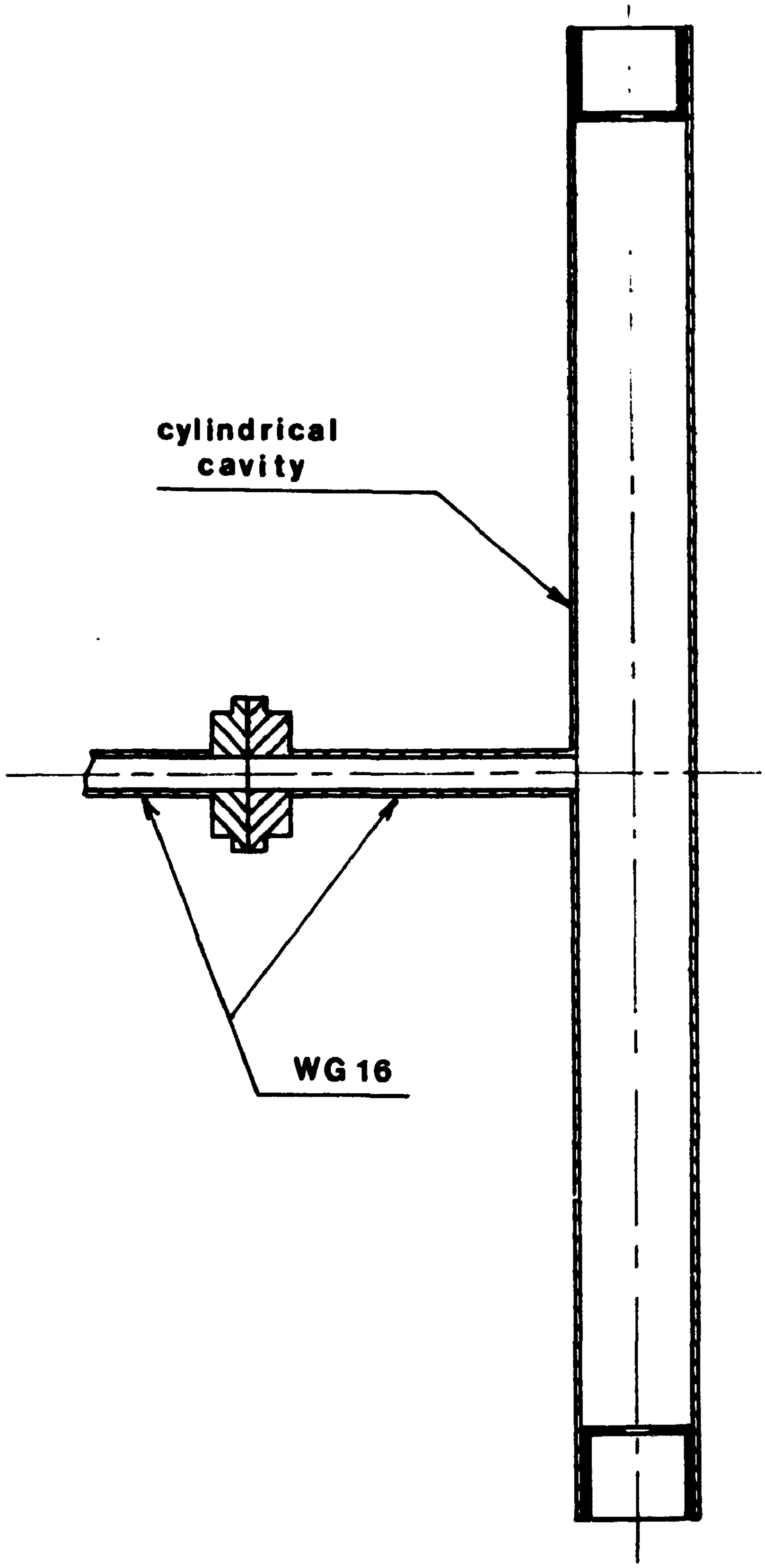



**Figure 3.** Set-up with a long cylindrical cavity as the measuring unit.

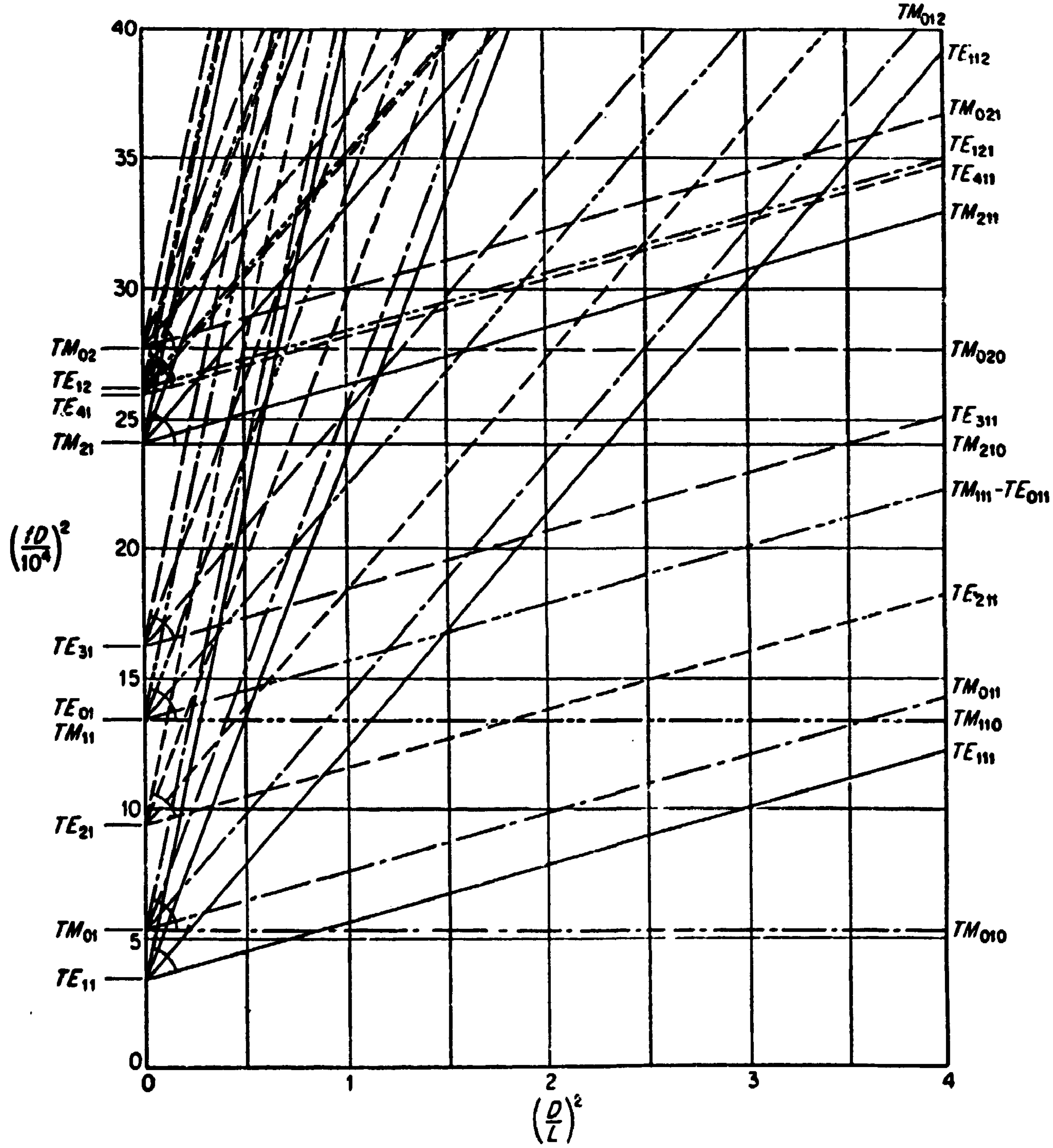
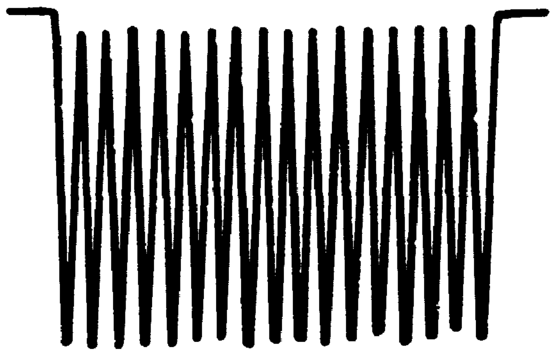
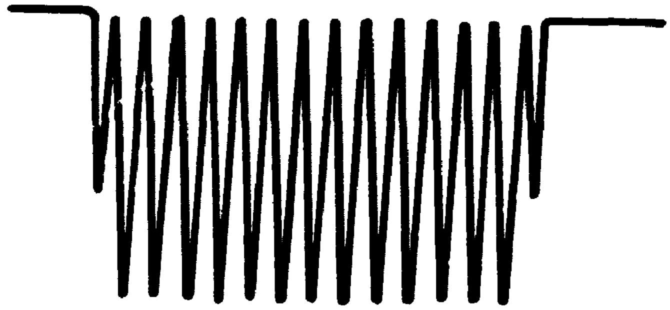



__Figure 4.__ Mode chart for a cylindrical cavity. D and L are the diameter and length of the cavity, respectively, in centimeters, and f is in MHz.



<u>Figure 5.</u> Qualitative signal from a pellet passing the cavity along the axis. The horizontal direction may be taken as the position of the pellet or the time of flight. The cavity is in the $TE_{11}$ mode.



<u>Figure 6.</u> Qualitative signal from a pellet passing the cavity along the axis. The horizontal direction may be taken as the position of the pellet or the time of flight. The cavity is in the $TM_{01}$ mode.

and $TM_{01}$ mode, respectively. The time of entrance and exit of the pellet in the cavity is easily seen, and as the length of the cavity is known, or the number of half wavelengths is easily counted, it is possible to calculate the velocity of the pellet. Figure 5 shows the signal when the $TE_{11}$ mode is excited. In this case seventeen half wavelengths were measured as having a length of 36.2 cm, corresponding to 2.13 cm per half wavelength. This figure is in excellent agreement with 2.17 cm expected from the mode chart. Figure 6 shows a situation where $TM_{01}$ is excited. As the outermost peaks correspond only to half periods, we have fourteen half wavelengths in all for a cavity length of 36.9 cm, now giving 2.64 cm per half wavelength. Again we have fine agreement with the expected value of 2.65 cm from the mode chart.

To be sure to have the best coupling between the transmission line and the cavity, the input position of the transmission line into the cavity has been shifted around the symmetrical position. In the case with $TM_{01}$ mode in the cavity, it is seen from Figure 7 that the centre position gives the best coupling. This is what should be expected, because in this situation a good harmony exists between the electric field in the transmission line and in the cavity. For the $TE_{11}$ mode with an odd number of half wavelengths in the cavity, the centre position gives poor conditions for a reasonable coupling. This is clearly seen in Figure 8. Shifted a quarter of a wavelength good harmony exists between the magnetic fields in the

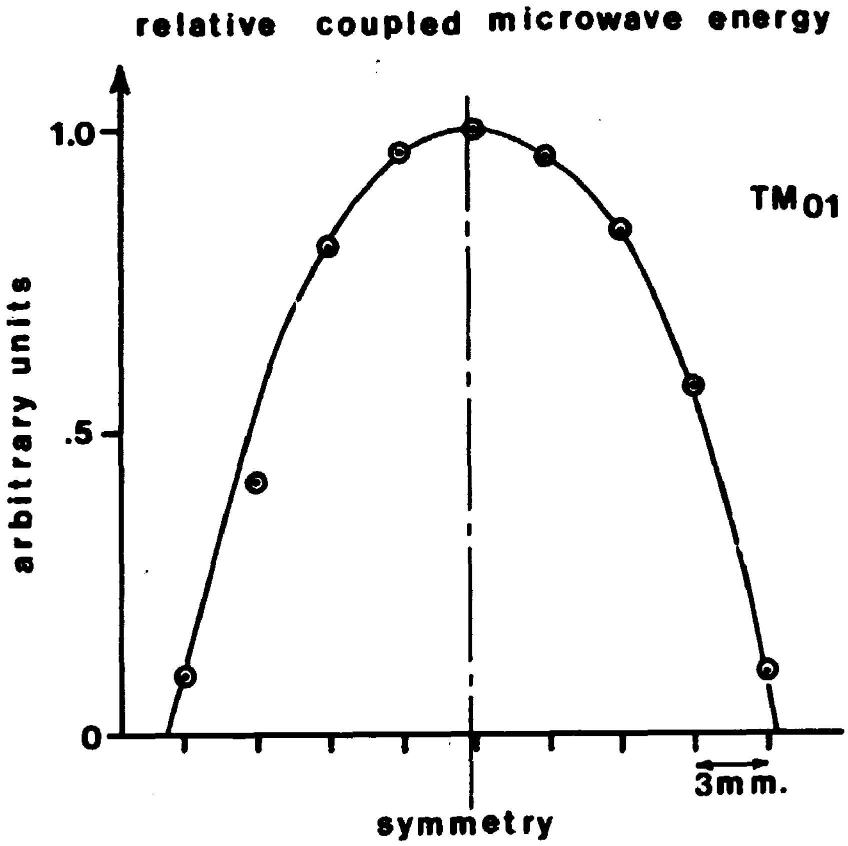



Figure 7. Relative coupling between transmission line and cavity versus input position in the $TM_{01}$ mode. The symmetry position indicates equal distance to the two end walls.

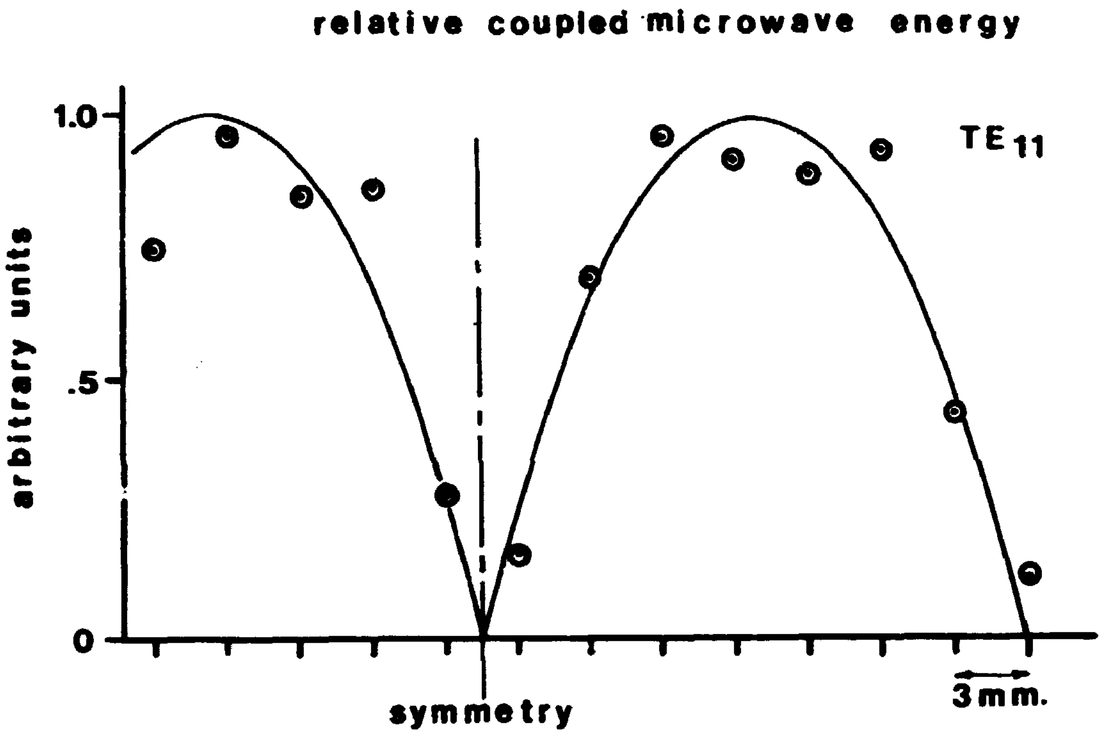



Figure 8. Relative coupling between transmission line and cavity versus input position in the $TE_{11}$ mode. The symmetry position indicates equal distance to the two end walls.

transmission line and in the cavity. Good coupling in the symmetrical position could have been obtained by turning the WG 16 waveguide 90 degrees around its own axis before soldering it to the cavity. In the following the optimal coupling positions have been used for the two modes.

Pellet injectors are unable to inject pellets precisely along a given line in each shot. The larger the pass-holes in the cavity, the larger will be the allowed scattering angle of the pellets. The influence of the size of the pass-holes, by decreasing the Q-value of the cavity, has been investigated, and the signal from a dummy pellet versus the hole-size has been shown in Figure 9 for the $TE_{11}$ mode. The $TM_{01}$ mode acts in a similar way. It is seen that for the set-up used, the pass-holes should not exceed about 10 mm in diameter. If the aiming accuracy of the pellet injector demands larger holes, the whole system may be scaled up by using another oscillator with a lower frequency.

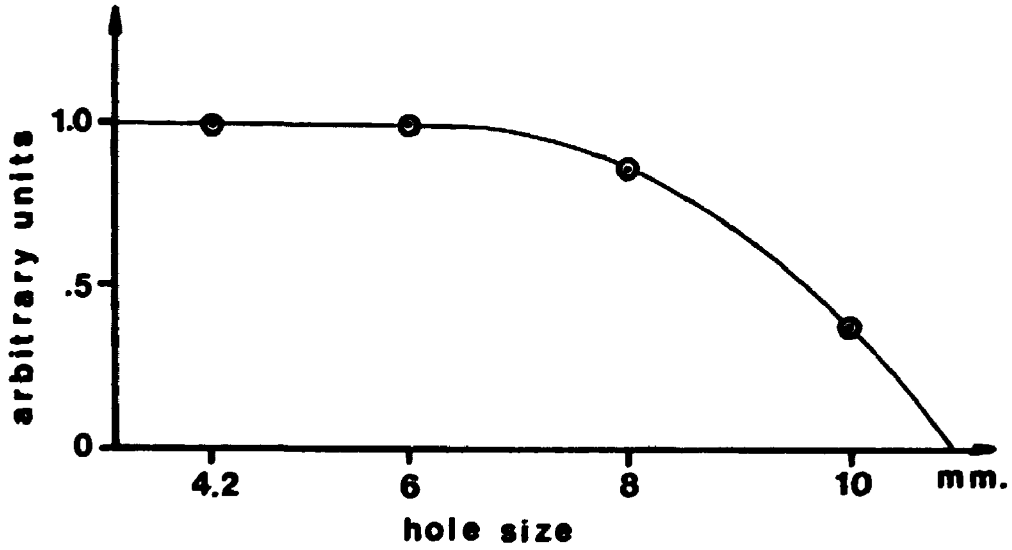



Figure 9. Relative sensitivity of the cavity versus diameter of the holes in the end walls for the $TE_{11}$ mode.

Another problem in relation to the need of large holes is that the signal from the microwave detector, because of the insertion of the pellet, is influenced by the radial position of the pellet. Figures 10 and 11 show the relative signal at 10 mm pass-holes along two perpendicular axes for the $TE_{11}$ and $TM_{01}$ modes, respectively. In both cases the signal is seen to be symmetrical around the centre, when the axis is perpendicular to the axis of the transmission line. Along this axis a non-symmetrical

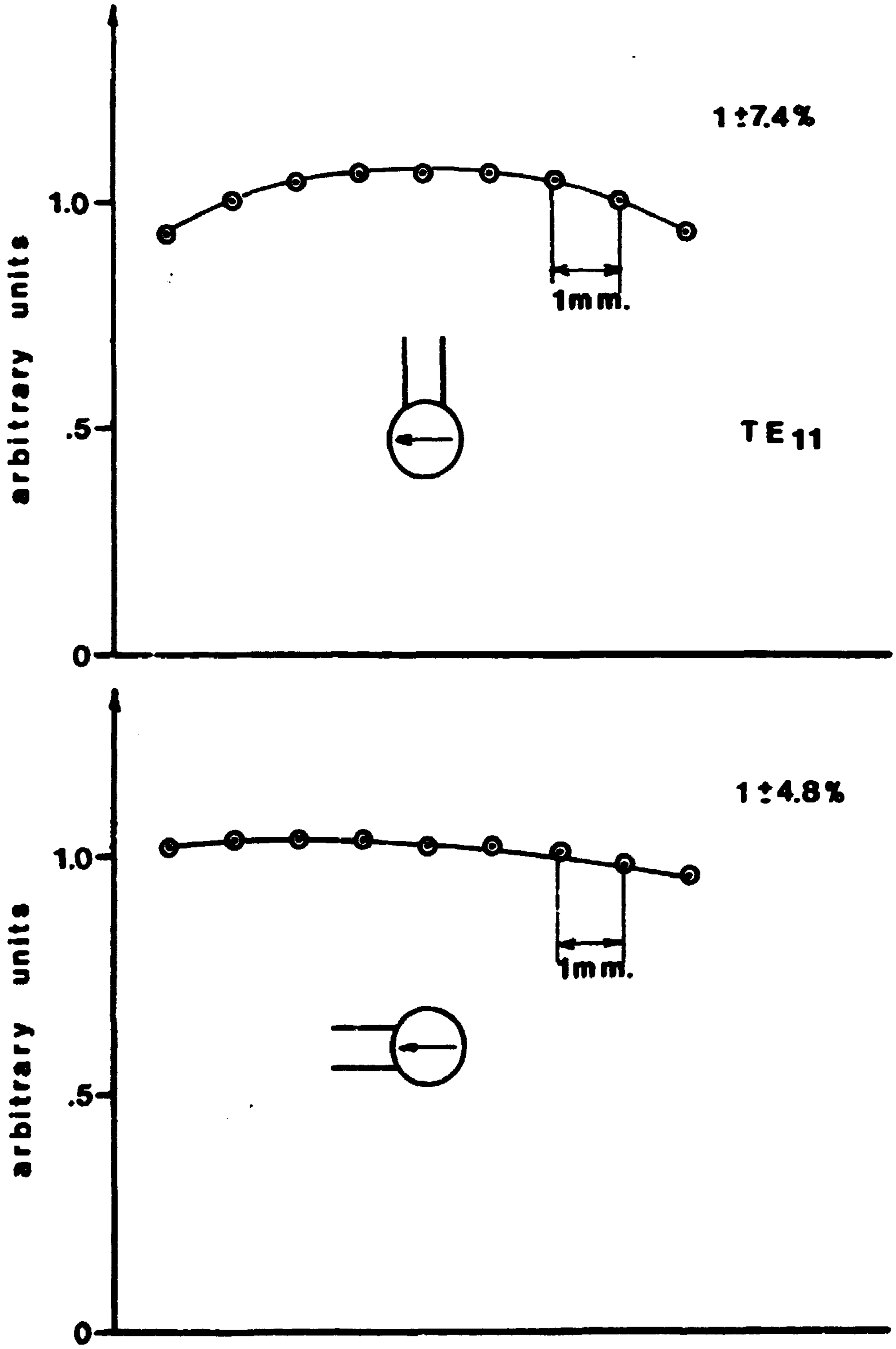



Figure 10. Relative sensitivity of the cavity versus the radial position of the pellet in the $TE_{11}$ mode perpendicular to and in the direction of the axis of the transmission line.

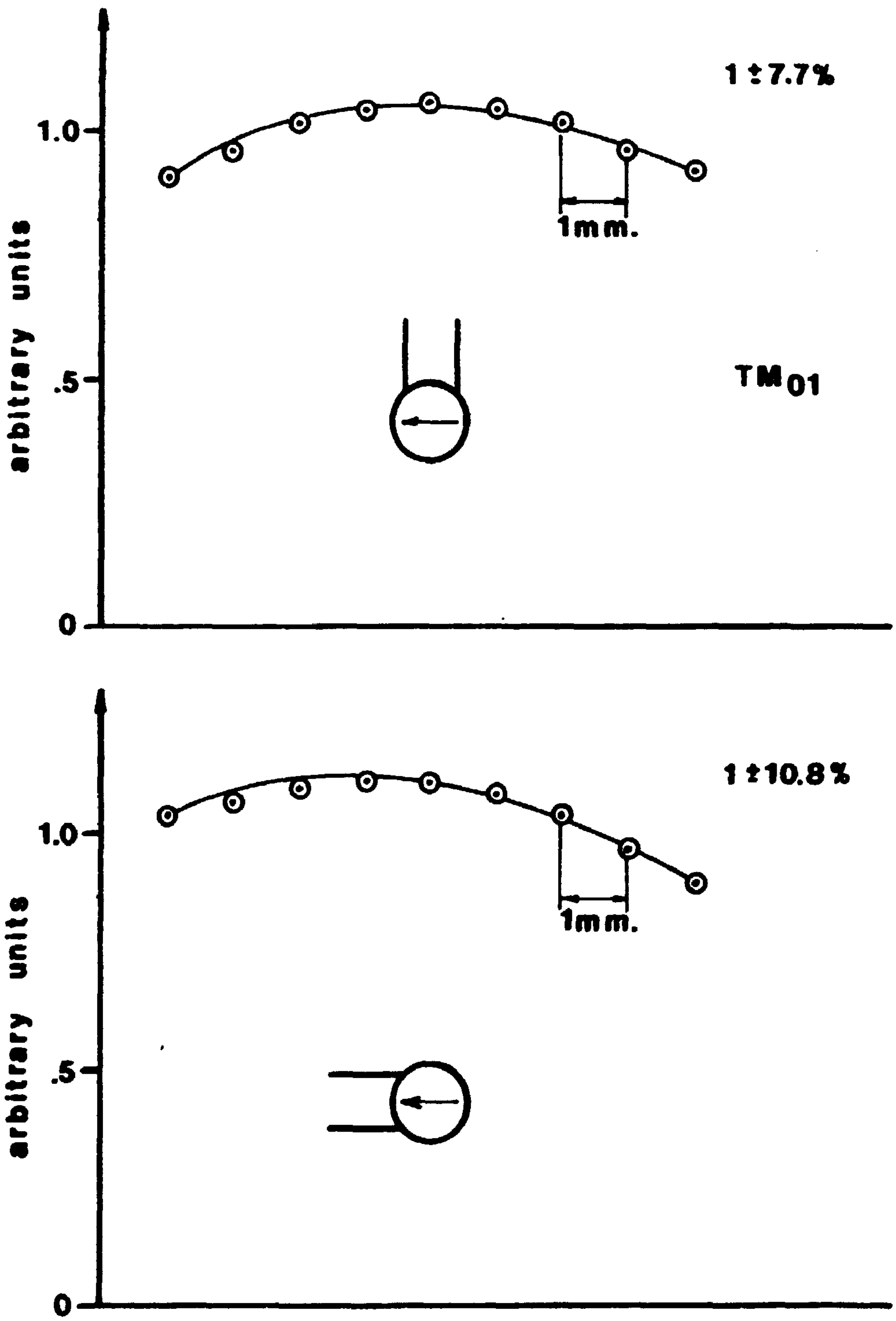
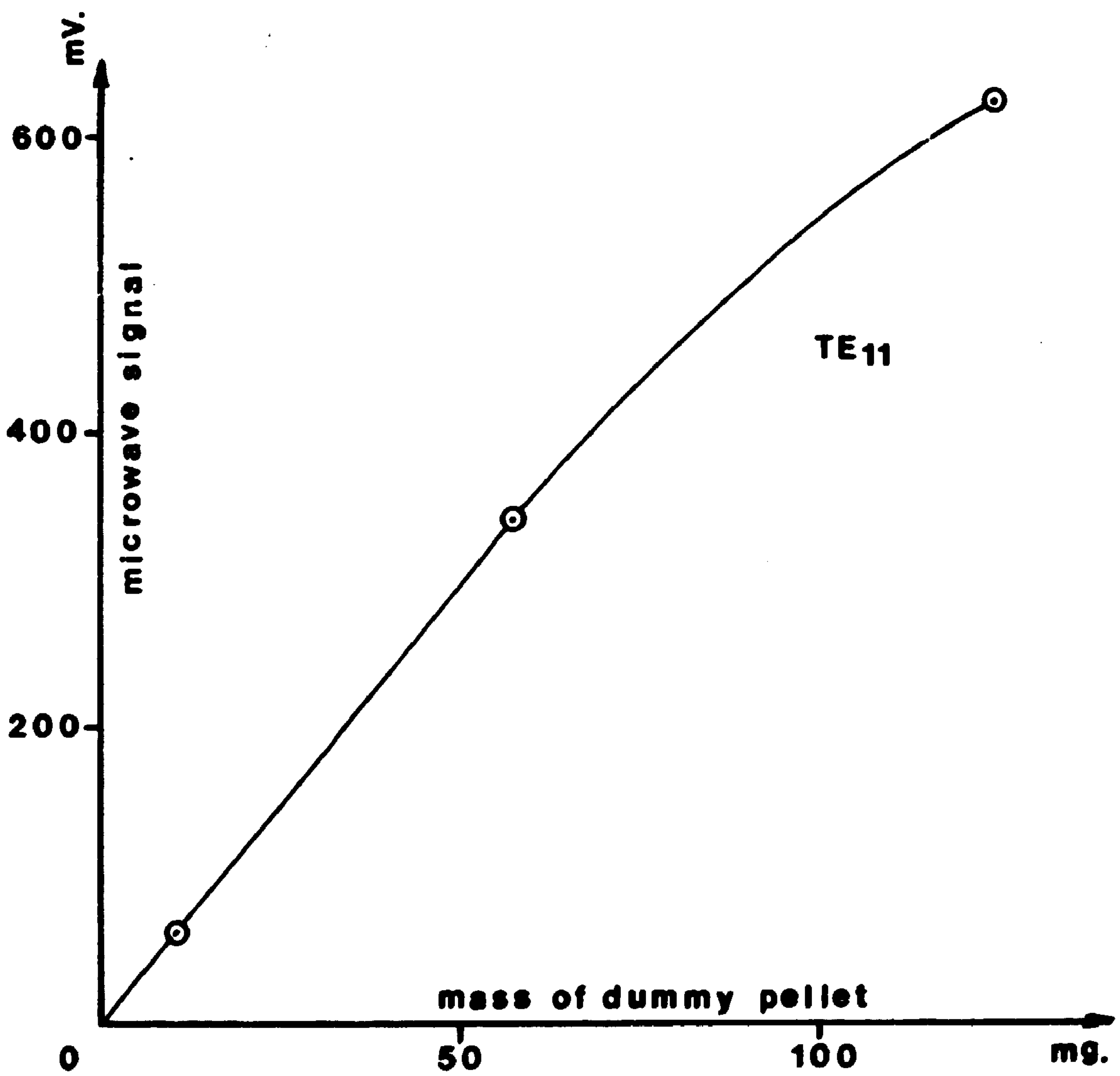



Figure 11. Relative sensitivity of the cavity versus the radial position of the pellet in the $TM_{01}$ mode perpendicular to and in the direction of the axis of the transmission line.

effect is seen. In the worst case the relative deviation is about ± 10%, and it is seen that in this respect the $TE_{11}$ mode is to be preferred with about ± 7% in one direction and about ± 5% in the other. These diviations are diminished if smaller pass-holes are allowed.

In a suitable set-up the amplitude of the oscillations shown in Figure 5 or 6 will be proportional to the mass of the pellet[1]. The working-point of the system should be taken on the flank of the resonance peak, allowing the shift, because of the entrance of the pellet, to take place along the linear part of the flank. The linearity of the system versus mass of the pellet is shown in Figures 12 and 13 for the two modes, respectively. It is seen that in both cases we find a good linearity for pellet sizes up to about 75 mg of our Teflon dummy pellets. This corresponds to a cylindrical deuterium pellet with diameter and length equal at about 5 mm.

In Figures 12 and 13 the microwave signal has been given as the output in mV from the detector, to indicate the size of signal that may be obtained, using a 1N23 diode as detector and a 100 mW Gunn-diode as a source.




<u>Figure 12.</u> Linearity of the system versus the size of dummy pellets. The diameter of the pass holes is 10 mm. The cavity is in the $TE_{11}$ mode.

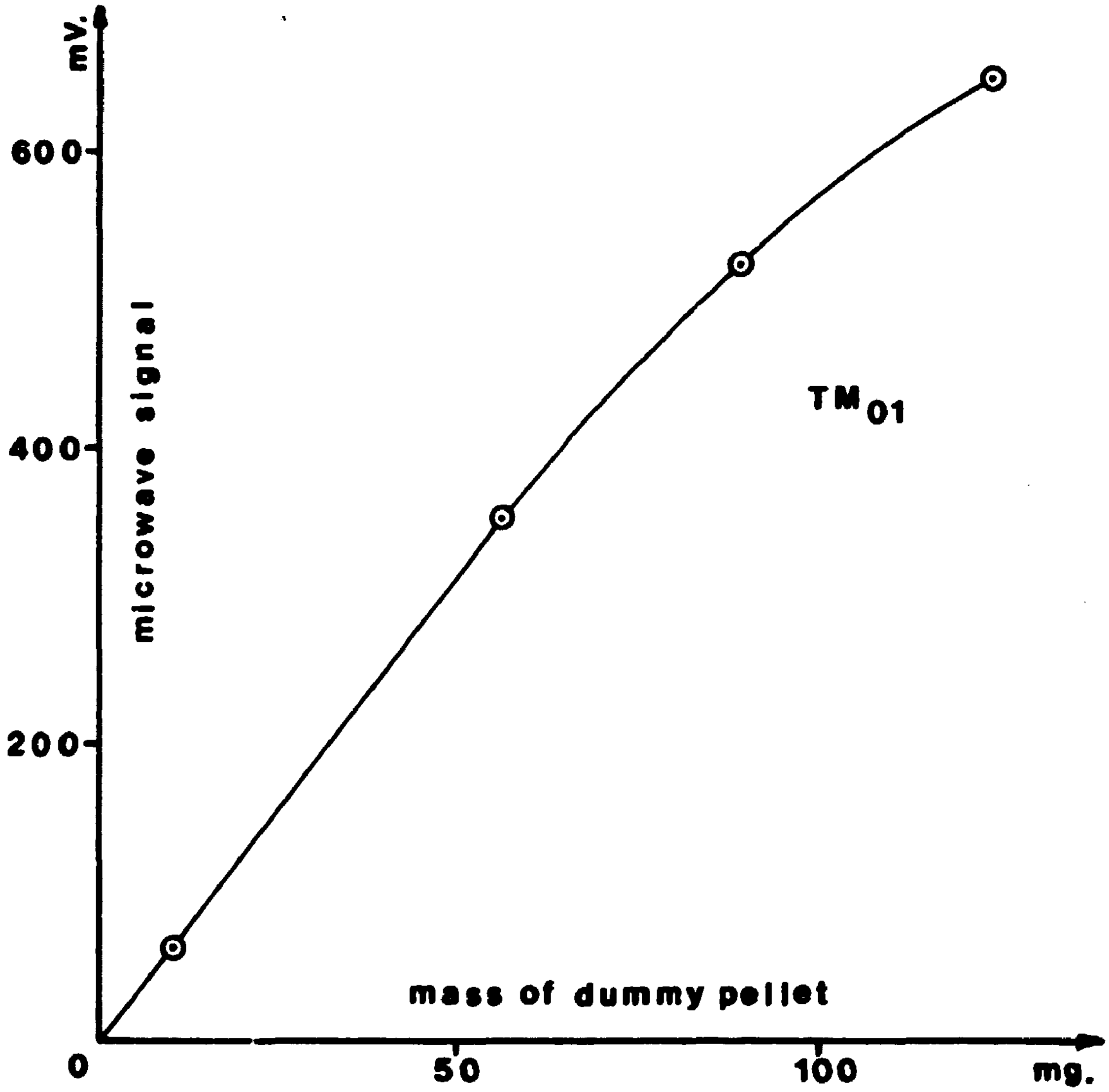



Figure 13. Linearity of the system versus the size of dummy pellets. The diameter of the pass holes is 10 mm. The cavity is in the $TM_{01}$ mode.

## Conclusion

Diagnostic equipment suited to mass and velocity measurements of pellets in flight has been demonstrated. It is simple in that it carries out both measurements with only one arrangement, and easy to tune in using only one measuring cavity. The system may be reasonably compact, or the active elements may be placed up to about 20 m from the measuring unit, if radiative environments require it.

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CAVITY RESONATORS; DEUTERIUM; DIAGNOSTIC TECHNIQUES; DIELECTRIC MATERIALS; PELLET INJECTION; MEASURING METHODS; NONDESTRUCTIVE TESTING; PELLETS; TOKAMAK DEVICES; VELOCITY


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